

## SPECIFICATION

5 SWIRL CHAMBER USED IN ASSOCIATION WITH A  
COMBUSTION CHAMBR FOR DIESEL ENGINES

## TECHNICAL FIELD

10 【0001】 The present invention relates generally to a combustion chamber for diesel engines, and more particularly, to improvements upon a swirl chamber used in association with a combustion chamber for diesel engines.

## BACKGROUND ART

15 【0002】 In general, diesel engines are notorious as a major source of environmental contaminants such as NOx and fumes. However, no effective measures have been accomplished for solving those problems. It is known that these problems are due to the incomplete combustion in the engine occurring because of inadequate mixing of air and fuel. To solve these problems, swirl-aided combustion systems are commonly used. Here is one  
20 example for tackling this problem, which is disclosed in Japanese Patent Laid-open Application No. 07-97924. Referring to Fig. 10, the known combustion chamber fitted with a swirl chamber will be described:

25 【0003】 In Figs. 10A and 10B the right-hand side (toward the central axis 103) is called "rearward", and the left-hand side

(toward the cylinder liner 104) is "forward" each as designation for convenience only. The known combustion chamber shown in Fig. 10A is provided with a cylinder 101 having a cylinder head 105, a reciprocating piston 102, and a combustion chamber 109. In addition, the cylinder head 105 is provided with a recess 106 in which a mouthpiece 107 is fitted. The mouthpiece 107 is provided with a top-open recess 107a, and the recess 106 includes a bottom-open recess 106a. The top-open recess 107a and the bottom-open recess 106a constitute a space 108 functioning as a swirl chamber, hereinafter the space being referred to as "swirl chamber 108". The swirl chamber 108 communicates with the combustion chamber 109 through a main nozzle hole 111 having a center axis 113. The main nozzle hole 111 is forwardly inclined toward the swirl chamber 108. The mouthpiece 107 is additionally provided with a pair of sub-nozzle holes 112, through which a secondary air is forced into the swirl chamber 108 on the compression stroke. The sub-nozzle holes 112 are symmetrically positioned on opposite sides of the central axis 113-114 as shown in Fig. 10A.

20    **【0004】** Under the construction mentioned above, however, a major disadvantage is that the second air ejected through the sub-nozzle holes 112 does not reach the central part of the swirl chamber 108, thereby failing to bring about effective swirls therein. In this way the conventional sub-nozzle holes 112 are not conducive to the full utilization of the secondary air.

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【0005】 The disadvantages mentioned above is due to the following arrangement of the sub-nozzle holes 112: When a hypothetical circle (actually, sphere) 115 is supposed about the center of the open end 107b of the top-open recess 107a, and the radius of the open end 107b and that of the circle 115 are respectively supposed to be 100% and 70%.

The circle 115 having a radius of 70% passes outward, whereas the circle 115 having a radius of 50% passes inward in Figs. 10A and 10B. In this situation, the central axis 112a-112b of each of the sub-nozzle holes 112 passes outside the circle 115.

【0006】 In another aspect, the sub-nozzle holes 112 have their center 112c deviated from the center of the swirl chamber 108 so that the central axis 112a-112b of each sub-nozzle hole 112 cannot pass inside the 50% circle 115.

【0007】 Accordingly, an object of the present invention is to provide an improved swirl chamber capable of causing effective swirls to help air and fuel being well mixed, and dispersing the fuel well in the swirl chamber.

【0008】 Another object of the present invention is to provide an improved swirl chamber capable of reducing the production of both NO<sub>x</sub> and fumes, not one or the other under the conventional system.

### SUMMARY OF THE INVENTION

【0009】 According to the present invention, a swirl chamber used in association with a combustion chamber, wherein the combustion

chamber is defined by a piston, a cylinder, and a cylinder head, includes a mouthpiece fitted in a hole of the cylinder head, the hole having a bottom-open recess, and the mouthpiece including a top-open recess, the bottom-open recess and the top-open recess constituting a space for the swirl chamber; a main nozzle hole produced through a base wall of the mouthpiece to allow the swirl chamber to effect communication between the combustion chamber and the swirl chamber; and a pair of sub-nozzle holes produced through the base wall of the mouthpiece, the holes being positioned symmetrically on opposite sides of the central axis of the main nozzle hole; wherein each of the sub-nozzle holes is arranged to pass inside a hypothetical first circle having a radius of 70% of that (100%) of a hypothetical second circle depicted around the center of the top-open recess.

#### BRIEF DESCRIPTION OF THE DRAWINGS

【0010】 Fig. 1 is generally a diagrammatic view exemplifying a first embodiment of the present invention; Fig. 1A being a plan view, Fig. 1B being a cross-sectional view taken along the line B-B of Fig. 1A; Fig. 1C being a bottom view, and Fig. 1D being a cross-sectional view taken along the line D-D;

【0011】 Fig. 2 is generally a diagrammatic view exemplifying the nozzle hole in the mouthpiece shown in Fig. 1; Fig. 2A being a vertical cross-sectional side view of the mouthpiece, Fig. 2B being a perspective view of the nozzle hole; Fig. 2C being a diagrammatic view of the nozzle hole viewed in the direction indicated by the

arrow C in Fig. 2A, and Fig. 2D being a bottom view of the nozzle hole;

5     【0012】 Fig. 3 is generally a diagrammatic view exemplifying the swirl chamber shown in Fig. 1; Fig. 3A being a horizontal cross-sectional plan view of a cylinder incorporating a piston, and Fig. 3B being a cross-sectional side view of the swirl chamber and the surrounding part members;

10     【0013】 Fig. 4 is a graph showing NOx content in the exhaust gases under the first embodiment shown in Fig. 3, in comparison with a contrasted example 1 having no sub-nozzle holes;

   【0014】 Fig. 5 is a graph showing the amount of NOx and fumes exhausted under the first embodiment shown in Fig. 3, in comparison with contrasted examples 1 and 2;

15     【0015】 Figs. 6 is generally a graph showing the relationship between the cross-sectional area of the sub-nozzle holes and the characteristics of gases exhausted from the swirl chamber of Fig. 3; Fig. 6A showing variations in the amount of NOx in relation to the cross-sectional area; Fig. 6B showing variations in the amount of fumes in relation to the cross-sectional area; and Fig. 6C showing  
20     variations in the total amount of NOx and fumes in relation to the cross-sectional area;

   【0016】 Fig. 7 is generally a diagrammatic view exemplifying the mouthpiece of a second embodiment; Fig. 7A being a plan view, Fig. 7B being a cross-sectional view taken along the line B-B in Fig. 7A;  
25     Fig. 7C being a bottom view, and Fig. 7D being a cross-sectional

view taken along the line D-D in Fig.7B;

【0017】 Fig.8 is generally a diagrammatic view exemplifying the mouthpiece of a third embodiment; Fig. 8A being a plan view, Fig. 8B being a cross-sectional view taken along the line B-B in Fig. 8A; 5 Fig. 8C being a bottom view, and Fig. 8D being a cross-sectional view taken along the line D-D in Fig.8B;

【0018】 Fig. 9 is generally a diagrammatic view exemplifying the mouthpiece of a fourth embodiment; Fig. 9A being a plan view, Fig. 9B being a cross-sectional view taken along the line B-B in Fig. 9A; 10 Fig. 9C being a bottom view, and Fig. 9D being a cross-sectional view taken along the line D-D in Fig.9B; and

【0019】 Fig. 10 is generally a diagrammatic view exemplifying a known swirl chamber; Fig. 10A being a plan view of the mouthpiece and the piston, and Fig. 10B being a vertical cross-sectional side 15 view of a swirl chamber and surrounding part members.

#### DESCRIPTION OF PREFERRED EMBODIMENTS

【0020】 Throughout the drawings like numerals are used to designate like components, and in Figs. 1B, 3B, 7B, 8B, 9B, and 2A the right-hand side is “forward”, and the left-hand side is 20 “rearward” for convenience of illustration only. A first embodiment is shown in Figs. 1 to 6, in which a pair of sub-nozzle holes 12 are provided upright in parallel with the central axis 3 of a cylinder 1. This is the same with a second embodiment shown in Fig. 7, but in the third embodiment shown in Fig. 8 and a fourth embodiment 25 shown in Fig. 9 the sub-nozzle holes 12 are slightly converged and

slightly diverged toward their top open ends, respectively. The feature common with all the embodiments is that the sub-nozzle holes are spaced from, and positioned symmetrically on opposite sides of, the main nozzle hole. In addition, the sub-nozzle holes are  
5 produced on the forward side.

【0021】 In Fig. 3B a reciprocating piston 2 is provided inside a cylinder 1 along whose central axis 3 the piston 2 moves up and down. The cylinder 1 has a head 5 having a recess 6 in which a mouthpiece 7 is fitted. The recess 6 includes a bottom-open recess  
10 6a, and the mouthpiece 7 includes a top-open recess 7a. The bottom-open recess 6a and the top-open recess 7a constitute a space 8 that is utilized as a swirl chamber. The cylinder 1 is provided with a combustion chamber 9 having a main nozzle hole 11 passing through the mouthpiece 7. The combustion chamber 9 and the  
15 swirl chamber 8 communicate with each other through the main nozzle hole 11, which is forwardly inclined toward the swirl chamber 8 from the combustion chamber 8, as shown in Fig. 3B. The mouthpiece 7 has an undersurface 7d in a plane perpendicular to the central axis 3 of the cylinder 1.

20 【0022】 As best shown in Fig. 3B, a fuel jet nozzle 19 and a heat plug 20 are provided toward the swirl chamber 8. The piston 1 is provided with a triangular recess 21 adapted to guide a gas flow, wherein the root portion of the recess 21 is positioned immediately below the main nozzle hole 11, and as best shown in Fig. 3A, the  
25 recess 21 expands progressively far from the main nozzle hole 11,

thereby having a diminishing depth, as best shown in Fig. 3B.

【0023】 The principle underlying the combustion chamber 9 fixed with the swirl chamber 8 is as follows:

On the compression stroke the piston 2 rises, thereby  
5 introducing compressed air into the swirl chamber 8 to cause swirls therein. When the piston 2 reaches the top dead point, fuel is ejected through the ejection nozzle 19. The fuel is mixed with the air in the swirl chamber 8, and the charge of fuel and air is ignited, and burned in the chamber 8, and as a result, it expands in volume.  
10 The expanded gases pass into the combustion chamber 9 through the main nozzle hole 11. The fresh charge expands and rises as it goes away from the main nozzle hole 11 in the triangular recess 21. The fuel-content in the fresh charge mixes with air in the combustion chamber 9, and the mixture is ignited and burned.

15 【0024】 The sub-nozzle holes 12 will be described:

In Figs. 1A to 1D, particularly in Figs. 1B and 1D, the sub-nozzle holes 12 are provided in pair through a base wall 10 of the mouthpiece 7. Each of the sub-nozzle holes 12 is away from the main nozzle hole 11 such that they are symmetrically positioned  
20 about the central axis 13 of the main nozzle hole 11 or about its extension 14, depending upon the shape of the main nozzle hole 11.

【0025】 Figs. 1A, 1B, and 1D show a hypothetical circle 15 (actually, a sphere) about a center 7c which is the center of the open end 7b of the recess 7a. The radius of the open end 7b is supposed  
25 to be 100%, and that of the circle 15 to be 50%. Each of the



sub-nozzle holes 12 is positioned such that its central axis 12a-12b passes through the sphere 15, or in the drawing, through the circle 15.

【0026】 Preferably, the radius of the circle 15 is 70%; more preferably, 60%, and most preferably, 50%. In Figs. 1A, 1B, and 1D the innermost, middle, and outermost circles 15 are drawn in correspondence to 50%, 60%, and 70%, respectively. It has been demonstrated that this range of angular positioning of the sub-nozzle holes 12 enables a secondary air to gather at the center of the swirl chamber 8, thereby making the most of the air ejected through the sub-nozzle holes 12 and causing effective swirls in the swirl chamber 8.

【0027】 Fig. 1A shows, as a preferred embodiment, that the center 12c of the open end of each sub-nozzle hole 12 coincides with the circle 15 having a radius of 50%, thereby enabling the central axis 12a-12b of each sub-nozzle hole 12 to pass through the center of the swirl chamber 8. In this case, the radius is preferably 70%, more preferably 60%, and most preferably 50% of that (100%) of the open end of the top-open recess 7b.

【0028】 In Figs. 1A and 1D, a hypothetical reference line 16 is supposed to extend from the central axis 12a of each sub-nozzle holes 12 by which the position of each hole 12 is determined; that is, each sub-nozzle hole 12 is positioned such that its central axis 12a-12b coincides with the reference line 16 in every direction as viewed in Figs. 1A to 1D.

5       【0029】 In this way the sub-nozzle holes 12 are positioned at various angles for the reference line 16 (Figs. 1B and 1D). If it is positioned at a relatively large angle to the reference line 16, the sub-nozzle hole 12 can be short in length, thereby reducing frictional resistance to the flow of a secondary air passing through the sub-nozzle hole. In Fig. 1B where the cross-section of the mouthpiece 7 is viewed from the side, and the two sub-nozzle holes 12 appear to be in alignment, the central axis 12a-12b of the sub-nozzle hole 12 is preferably inclined at 30° or less to the reference line 16, which will be referred to as “first angle”. In Fig. 1D where the cross-section of the mouthpiece 7 is viewed from the back, and the sub-nozzle holes 12 appear to be arranged side by side, the central axis 12a-12b is preferably inclined at 15°, which will be referred to as “second angle”. In another preferred embodiment the first angle is 15° or less, and the second angle is 8° or less; more preferably, 8° or less to 4° or less, and most preferably, 4° or less to 2° or less.

20       【0030】 In the embodiment illustrated in Figs. 1B and 1C the first angle is 30° and the second angle is 15° each angular relation being indicated by chain lines.

      【0031】 The size of each sub-nozzle hole 12 is determined as follows:

      It has been demonstrated that when the main nozzle hole 11 has an open end having an effective area is supposed to be 100%, the total area of the open ends of the two sub-nozzle holes should

be in the range of 3% to 15%; preferably, 4 to 10%; more preferably, 6 to 10%, and most preferably, 7 to 9%. In short, the range of 3 to 15%, or preferably, of 5 to 15% is effective to reduce the production of NO<sub>x</sub> and fumes evenly.

5    **【0032】** The main nozzle hole 11 is constructed as follows:

Referring to Figs. 2A to 2D, the main nozzle hole 11 includes a main groove 17 and a pair of side grooves 18 communicatively continuous to the main groove 17 through banks (not numbered). In Fig. 2A, each side groove 18 is formed such that its central axis  
10    18a is slightly behind the central axis 17a of the main groove 17. Each side groove 18 is also arranged that its angle of elevation is smaller than 45° of the axis 17a.

**【0033】** As best shown in Fig. 1A, each of the side grooves 18 gradually but slightly becomes narrower in width toward the depth  
15    of the main nozzle hole 11 while the main groove 17 remains the same along its full length. In addition the side groove 18 and the sub-nozzle hole 12 on the same side of the central axis 13 of the main nozzle hole 11 are aligned each other.

**【0034】** Referring Figs. 4 and 5, the major advantage of the first  
20    embodiment is that environmental contaminants such as NO<sub>x</sub> and fumes are reduced in the exhaust gases, which will be demonstrated, on condition that the applied load is the same:

**【0035】** From Fig. 4, it will be understood that the first  
embodiment has less nitrogen oxides (NO<sub>x</sub>) than a contrasted  
25    example (1) that has neither sub-nozzle holes 12 nor the side

grooves 18. It will be appreciated that the sub-nozzle holes 12 and the side grooves 18 are effective to reduce NOx content.

【0036】 Fig. 5 shows that the first embodiment has less NOx and less fumes than contrasted examples 1 and 2, wherein the  
 5 contrasted example 2 has sub-nozzle holes corresponding to the sub-nozzle holes 12 but no grooves corresponding to the side grooves 18. The comparison between the contrasted examples 1 and 2 shows that the addition of the secondary air sub-nozzle holes 12 are conducive to the reduction of NOx and fumes. Likewise, the  
 10 comparison between the first embodiment and the contrasted example 2 shows that the side grooves 18 are conducive to the reduction of NOx and fumes.

【0037】 The efficiency of reducing exhaust gases depends upon the area of the open end of the sub-nozzle hole 12. Referring to Fig.  
 15 6A to 6C, each horizontal co-ordinate is the percentage of the total minimum area of the open ends of the sub-nozzle holes 12 to the area of the open end of the main nozzle hole 11. The vertical co-ordinate of Fig. 6A indicates variations in the amount of NOx; in Fig. 6B the vertical co-ordinate indicates variations in the amount  
 20 of fumes, and in Fig. 6C the vertical co-ordinate indicates variations in the total amount of NOx and fumes. Each coefficient of variation is calculated, as a reference value, based upon the amount of NOx and fumes produced in the combustion chamber having no  
 sub-nozzle holes 12. Let the reference value be  $\alpha$ , and the amount  
 25 of variation be  $\beta$ . Then, the coefficient of variation will be  $(\beta - \alpha)/$

$\alpha$ .

【0038】 As shown in Fig. 6C, the absolute value of the total reduction rate is maximized when the area of the open end of the sub-nozzle holes 12 is 7.7%. Let the absolute value of the reduction rate at this stage be 100%. It has been demonstrated that to increase the rate of reduction of exhaust gases up to 98%, the total area of the open ends of the sub-nozzle hole 12 must be in the range of 7 to 9%, and if it is in the range of 95% to 98%, the total area can be in the range of 6 to 10%. If it is in the range of 60% to 95%, the total area can be in the range of 3 to 15%. Among these ranges, when it exceeds 70%, and both NO<sub>x</sub> and fumes begin to reduce, the total area is in the range of 4 to 10%. As a result, it will be concluded that the total area of the open ends of the sub-nozzle holes preferably in the range of 3 to 15%; more preferably, 4 to 10%, further preferably, 6 to 10%, and most preferably, 7 to 9%.

【0039】 Referring to Figs. 7, 8 and 9, a second embodiment, a third embodiment and a fourth embodiment will be described, respectively:

【0040】 In the second embodiment shown in Fig. 7 the total area of the open ends of the sub-nozzle holes 12 is 8% of the area (100%) of the open end of the main nozzle hole 11, wherein each sub-nozzle hole has an open end having the same area. This embodiment reduces the production of NO<sub>x</sub> or fumes or both, as clearly demonstrated by comparison with the contrasted examples 1 and 2.

【0041】 In the second embodiment the total area of the open end

of the sub-nozzle holes 12 is 8% of that (100%) of the open end of the main nozzle hole 11, wherein each sub-nozzle hole 12 has an open end having the same area. It has been demonstrated that the second embodiment reduces the production of NO<sub>x</sub> and fumes, as compared with the contrasted examples 1 and 2 as clearly demonstrated by comparison with the contrasted examples 1 and 2 in Fig. 4.

【0042】 In the third embodiment shown in Fig. 8 the pair of sub-nozzle holes 12 are inclined inwardly or, in other words, slightly converged toward the swirl chamber 8 from the combustion chamber 9 in contrast to the first and second embodiments where they extend upright between the combustion chamber 9 and the swirl chamber 8. In Fig. 8B the angle of incline is 30° and in Fig. 8D, the angle of incline is 15° toward each other.

【0043】 In the fourth embodiment shown in Fig. 9A to 9D, the pair of sub-nozzle holes 12 are inclined rearward, as best shown in Fig. 9B, and, as shown in Fig. 9D, are inclined outwardly or, in other words, slightly diverged toward the swirl chamber 8 from the combustion chamber 9. In Fig. 9B the angle of incline is 30° and in Fig. 9D, the angle of incline is 15° toward each other.